REVEGETATION OF NINE SQUARE MILES OF COPPER TAILINGS

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ABSTRACT

The permanent closure of approximately 5,500 acres of copper tailings at the White Pine Mine Tailings in the upper peninsula of Michigan was performed over a four-year period. The most important component of the closure plan in terms of cost and meeting water quality criteria was the design and implementation of a revegetation plan that would control wind and water erosion on the tailings by establishing a low/no maintenance, self-sustaining vegetative cover without the use of imported topsoil. This component saved the owner over $100,000,000 over importation of topsoil. To meet these requirements the revegetation approach employed included extensive site examination, selection of locally available sources of organic amendments, design and execution of greenhouse trials and on-site revegetation trials, development of reclamation specifications, full-scale implementation, and revegetation performance monitoring. By incorporating a paper mill sludge/wood chips mixture, balancing inorganic fertilizer additions, identifying effective erosion control techniques and selecting adapted plant species a highly extensive revegetation plan was developed and implemented on site.

INTRODUCTION

A mine closure program was initiated to permanently close 5500 acres of copper tailings at the White Pine Mine (WPM) Tailings in the upper peninsula of Michigan. The most important component of the closure plan in terms of cost and meeting water quality criteria was to design and implement a revegetation plan which would control wind and water erosion on the tailings and establish a self-sustaining vegetative cover without the use of imported topsoil and long-term maintenance. The existing regulatory approved method of closure included placement of a minimum of two feet of topsoil over the tailings. In reality, at least three feet of cover would need to be placed to bridge over the soft tailings. This equates to over 26 million cubic yards. At a minimal cost estimate to excavate, load, haul and place this material at $4.00 per cubic yard, the cost would have been over $100,000,000. Therefore, the costs related to developing a direct tailings revegetation approach were justifiable. The technical approach for the direct revegetation of the tailings included:

- Review of existing data
- Collection of soils and vegetation data

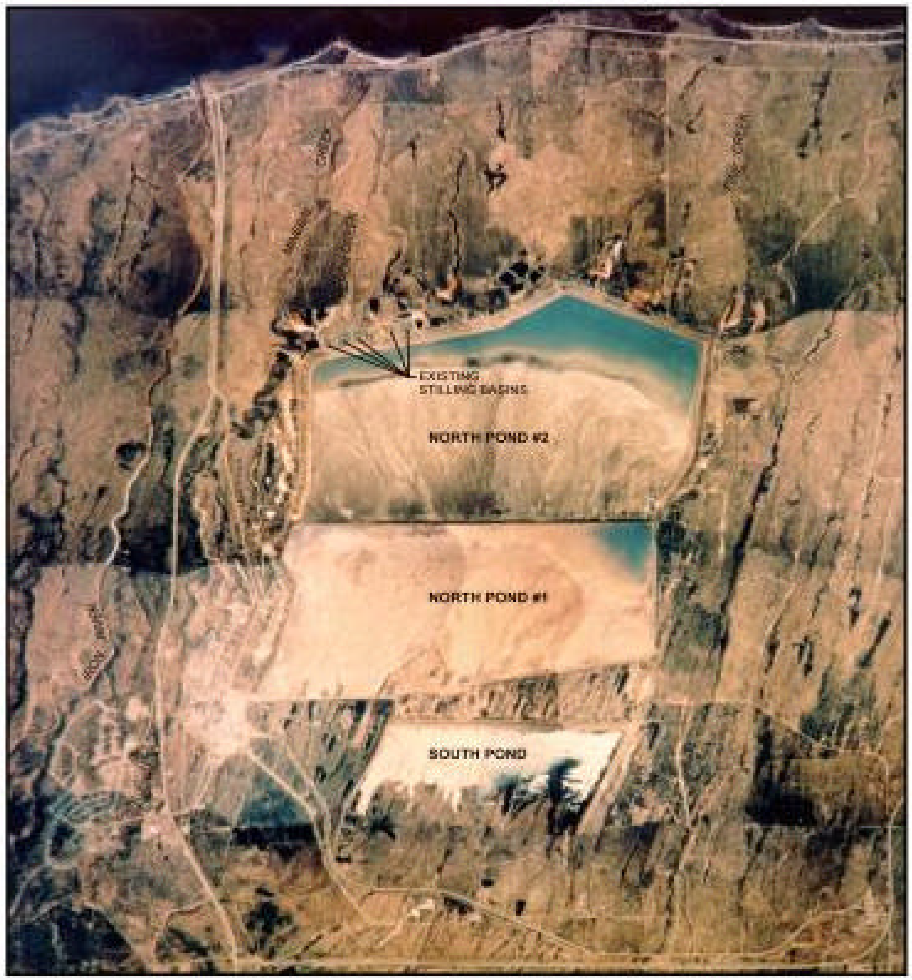
- Identification of local sources of soil amendments (e.g. paper mill sludge, wood waste, composted bark, etc.)
- Performance of greenhouse trials designed to test organic amendment strategies, plant species performance, plant metal tolerances and micronutrient deficiencies.
- Establishment of on-site revegetation trials to test the effectiveness of erosion control methods and the field performance of organic amendments and plant species selected in the greenhouse trials
- Provision of specifications for revegetation of the site
- Provision of quality assurance of the revegetation work
- Monitoring of the field trial and full-scale revegetation performance and modification of subsequent full-scale revegetation efforts.

The technical approach to the revegetation of the WPM Tailings proved successful due to the significant reduction in design development time, improved potential for revegetation success and the reduced risk of failure. This rational approach to reclamation and closure provided the continuity and organization essential for meeting the established success criteria at the lowest possible cost. Considering the size of the WPM Tailings, small changes in revegetation methods would significantly affect the total overall cost of tailings revegetation. Therefore, while research and development costs seemed onerous initially, long-term cost-benefits realized due to the ability to systematically diagnose the cause(s) of reclamation success and failure and rapidly modify and improve reclamation techniques during full-scale implementation.

BACKGROUND INFORMATION

The White Pine Mine located in Ontonagon County, Michigan (at approximate 47^{o} North Latitude) commenced operation in 1953 and operated through 1995. Approximately 300 million tons of copper ore (chalcocite {Cu_2S}) from the Nonsuch Shale formation were mined underground and processed (crushing and sulfide flotation). Tailings were discharged during the operations into three separate impoundments identified as North Pond 1, North Pond 2, and South Pond. The tailings were deposited by direct slurry discharge with surface pools maintained against the dams. The total amount of tailings deposited within the impoundments was estimated to be approximately 186 million tons. The total area covered by the ponds is approximately 5,500 acres. The climate in the region is characterized by a short growing season (June-Sept.), seasonal high winds and annual precipitation approximately 38 inches that mainly falls in the form of snow.

An aerial photograph of the three tailings impoundments of the WPM Tailings is provided below.



A tailings revegetation field trial program was initiated in the 1970's with limited success and data collection. Approximately 60 percent of North Pond 1 and 10 percent of North Pond 2 tailings support vegetation that naturally invaded the inactive and dry portions of the tailings impoundments over a 25-year period. The vegetation was primarily composed of Redtop (*Agrostis alba*) and Horsetail *(Equisetum spp.)* with infrequent and widely scattered stands of aspen/poplar (Populus tremuloides, *P. balsamifera* ,*P. grandidentata*), yellow birch (*Betula alleghaniensis*) and willow (Salix spp.). However, it is believed that the redtop was the only species surviving entirely on the tailings and the other species may be rooted, in part, in native soils beneath the tailings. The remaining portions of North Pond 1 and 2 and the South Tailings supported no vegetation.

COLLECTION OF SOILS AND VEGETATION DATA

A site investigation was performed to:

- Identify revegetation issues
- Develop a list of potential plant species for the revegetation of the tailings
- Identify candidate species for the greenhouse trials
- Evaluate the suitability and variability of the tailings matrix as plant growth medium
- Identify tailings physiochemical characteristics which could limit plant growth

Plant available copper (AB-DTPA extractable) was found to be well above levels considered in excess of critical levels for normal plant growth and substantially greater in the tailings than in "native" soils. Based on literature review porphyrin is present (approximately 2-5%) in the Nonsuch Shale. Porphyrin is a heterocyclic organic with a central metallic ion that forms the structural component of chlorophyll. Based on the concentrations of copper in water, weak acid and chelate extracts it is believed that porphyrin largely controls the plant availability of copper in the WPM tailings.

The range of geochemical characteristics of the tailings based on the sampling performed during the field survey are provided in **Table 1** below.

TABLE 1

pH (s.u.)	7.5-8.5
Electrical Conductivity (dS/m)	0.2-17
Base Saturation (%)	100
Total Sulfur (wt/%)	<0.01
Pyritic Sulfur (wt/%)	<0.01
Acid Generating Potential (Kg $CaCO_3$ /ton)	<0.03
Acid Neutralization Potential (Kg $CaCO_3$ /ton)	30-60
Copper (SPLP)	0.002-0.012 (mg/L)
Copper (AB-DTPA)	118-1295 (mg/Kg)
Lead (SPLP)	ND-0.01 (mg/L)
Lead (AB-DTPA)	ND-0.87 (mg/Kg)

TABLE 1	
Zinc (SPLP)	ND-0.038 (mg/L)
Zinc (AB-DTPA)	ND-3.28 (mg/Kg)
Arsenic (SPLP)	ND
Arsenic (AB-DTPA)	ND
Mercury (SPLP)	ND
Mercury (AB-DTPA)	ND
Cadmium (SPLP)	ND
Cadmium (AB-DTPA)	ND-0.91 (mg/Kg)
Nickel (SPLP)	-
Nickel (AB-DTPA)	0.38-2.84 (mg/Kg)

ND = Not detected - = not analyzed

The high levels of plant available copper shown above are known to adversely impact plant growth and development. Numerical thresholds for heavy metals in soils above which phytotoxicity is considered to be possible have been suggested. The copper levels promulgated by the United Kingdom are 140-280 mg/kg EDTA extractable (UK DOE-1987). H.J.M. Bowen (1979) suggested that soil concentrations above 250 mg/kg of total copper may result in phytotoxicity. Neuman, *et.al.*, 1987 suggested that AB-DTPA (ammonium bicarbonate-diethylenetriaminepentaaccetic acid) extractable copper levels between 50-210 mg/kg in mine soils from selected western coal mines were phytotoxic to plants.

Based on available literature, the plant availability of copper should be reduced by the addition of organic matter (OM) amendments. Solid-phase ligand formation is the mechanism responsible for decreases in copper toxicity to plants through the addition of peat and other sources of organic matter in high copper substrate (Soltanpour and Schwab, 1977). McLaren and Crawford (1973) showed that organic matter may form stable ligand complexes with soluble copper and maintain them in non-mobile forms. Baker (1990) indicated that organically bound copper is retained to the greatest degree in soils. In the presence of high levels of OM, humic materials and fulvic acids, the plant availability of copper is reduced through the formation of strong complexes with the OM and humates, resulting in slow dissociation rates (McBride, 1978, and Davies and Mertz, 1987). Stevenson (1982) found the stability constants of metal complexes with soil humic acid followed the order: copper > lead > cadmium > zinc. As a result of these previous findings the greenhouse study included an evaluation of the effectiveness of OM amendments on plant growth as well as the plant availability of copper and the influence of tailings born copper on plant growth and development.

The major revegetation issues identified as a result of the site investigation included:

- High Plant Available Copper Concentrations
- Low Organic Matter Content
- Nutritionally and Microbiologically Impoverished
- Moderate to High Salinity (No. 1 Tailings Impoundment)
- Wind Blown Tailings and Dune Formation
- Rill and Gully Erosion

- Surface Crusting
- Poor Infiltration and Aeration
- Clay and Silt Textures
- Inaccessible Tailings

IDENTIFICATION OF ORGANIC AMENDMENT SOURCES

High rates of inorganic fertilizers applied to a biologically inert material such as tailings typically do not facilitate the long-term plant nutrient cycling necessary to meet the goal of a self-sustaining vegetation cover. Over time with no OM incorporation the plant availability of inorganic fertilizer will decline and the supply of plant essential nutrients will be habitually reliant on continued fertilizer application. Therefore, one of the major tenants for the revegetation of WPM tailings was to control organic matter, nutrient inputs and species composition during reclamation to provide rapid nutrient cycling leading to improved ecosystem stability, ground cover and erosion control. As such, sources of OM amendments for the revegetation of the tailings were evaluated. The selection of OM was based on the following:

- Cost
- Distance from Site
- Regulatory Restriction
- Available Quantities
- Quality
    a. Metal Concentrations
    b. Particle Size Distribution
    c. Organic Carbon and Nitrogen Content (C:N ratio)
    d. Density
    e. Ash and Moisture Content
    f. Inorganic N, P and K
    g. Handling Requirements/Restrictions

The potential sources of OM included:

- Logging Waste
- Sawmill Waste
- Municipal Sewage Sludge
- Agricultural Waste
- Alfalfa or Straw Hay
- Wood Pulp Waste
- Commercially Available Organic Amendments

The approach to the amendation of the WPM Tailings was to provide a wide particle size range of OM, some of which decompose and supply nutrients quickly and others that decompose and supply nutrients more slowly. Therefore, woodchips were selected as an OM source that would provide the slowly available (long-term) nutrient source, while wood pulp sludge was selected to provide the readily available (short-term) source of nutrients for plant growth. Research has generally shown that application of fresh woodchips and other wood residues may result in the immobilization of nitrogen and subsequent nitrogen deficiency in plants grown on the amended material. Therefore, woodchips were supplemented with inorganic nitrogenous fertilizers according to its carbon:nitrogen ratio and the quantity applied to the tailings.

GREENHOUSE TRIALS

A twelve-week greenhouse study was implemented at Michigan Technical University. A four-way, randomized, complete block, factorial design was employed. This statistical design was utilized to assure the results were adequate for predictive purposes. Four levels of tailings, four levels of amelioration, 14 plant species, and five replicates resulted in 1,120 cells (or units). The soil amelioration categories included a control and three levels of organic matter additions. The organic matter amendment chosen was a mixture of paper mill sludge and wood chips. The species originally identified as having the necessary attributes for growing on tailings were narrowed down to 14 species. Statistical procedures were utilized to assure the results were adequate for predictive purposes.

Major Findings of the Greenhouse Study

The major findings of the greenhouse study were as follows

- Based on the performance of species evaluated in the greenhouse study the full-scale field trials seed mixture was formulated. The eight plant species with the greatest biomass production (**Table 2**) were selected for the trials.

TABLE 2
ABOVE GROUND BIOMASS BY SPECIES OVER ALL TAILINGS TYPES AND OM TREATMENTS

Species	Above Ground Biomass (g)
Alfalfa	0.35 (A)*
Hairy vetch	0.35 (A)
Orchardgrass	0.30 (A)
Volga mammoth wild rye	0.30 (A)
Smooth brome	0.21 (B)
Timothy	0.19 (BC)
Common reed	0.17 (BC)
Red fescue	0.14 (BCD)
Birdsfoot trefoil	0.12 (CDE)

TABLE 2
ABOVE GROUND BIOMASS BY SPECIES OVER ALL TAILINGS TYPES AND OM TREATMENTS

Species	Above Ground Biomass (g)
Redtop	0.07 (DEF)
American vetch	0.05 (EF)
American beachgrass	0.04 (EF)
Colonial bentgrass	0.04 (EF)
Queen Anne's lace	0.03 (F)

* Values with the same letter are not statistically different at the 0.05 level.

- Overall plant response increased as OM amendment addition increased (**Table 3**) and the minimum organic amendment rate which resulted in improved plant growth was determined.

TABLE 3
ABOVE GROUND BIOMASS
BY ORGANIC MATTER (OM) AMENDMENT LEVEL AVERAGED ACROSS ALL TAILINGS TYPES AND SPECIES

OM Level (%)	Above Ground Biomass (g)
5	0.19 (A)*
0	0.18 (AB)
3	0.16 (AB)
1	0.14 (B)

- Values with the same letter are not statistically different at the 0.05 level.

As organic matter amendment addition increased mycorrhizal infection increased (**Table 4**).

TABLE 4
EFFECTS OF ORGANIC MATTER (OM) AMENDMENT LEVEL ON MYCORRHIZAL INFECTION RATES AVERAGED ACROSS ALL SPECIES AND TAILINGS TYPES

OM Level (%)	Mean Infection Rate	Significance*
5	1.30	A
3	1.06	B
1	0.88	C
0	0.41	D

- Values with the same letter are not statistically different at the 0.05 level.

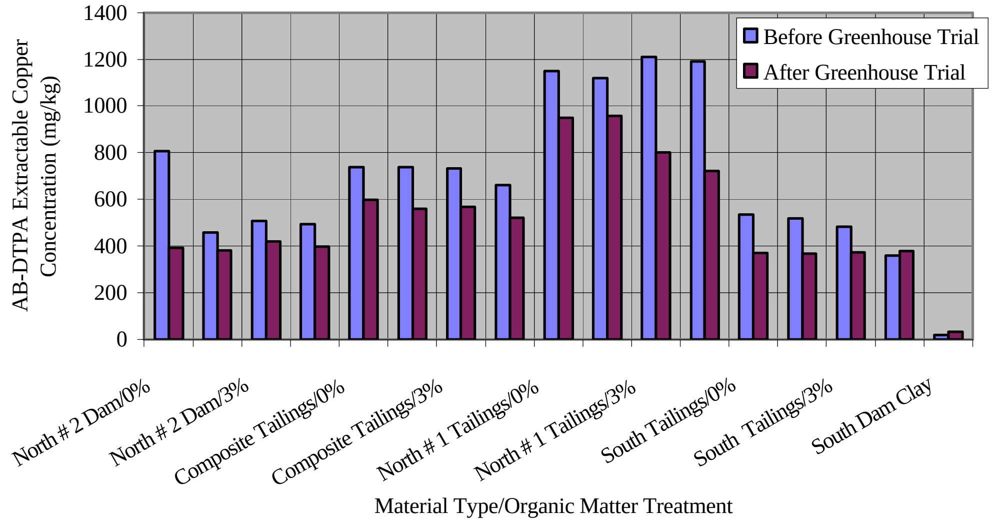
- The relative plant growth potential of each of the tailings types was identified (**Table 5**).

TABLE 5
ABOVE GROUND BIOMASS BY ORGANIC MATTER (OM) AMENDMENT LEVEL AVERAGED ACROSS ALL TAILINGS TYPES (EXCLUDING SD) AND SPECIES

Average of Foliage Wt	Tailings			
Organic Matter Percentage	**Barren**	**Vegetated**	**Coarse Sand Embankment**	**Grand Total**
0%	0.1325	0.0540	0.1326	0.1063
1%	0.0648	0.0322	0.0544	0.0505
3%	0.0772	0.0398	0.1262	0.0811
5%	0.1327	0.0618	0.2170	0.1371
Grand Total	0.1018	0.0469	0.1326	0.0937

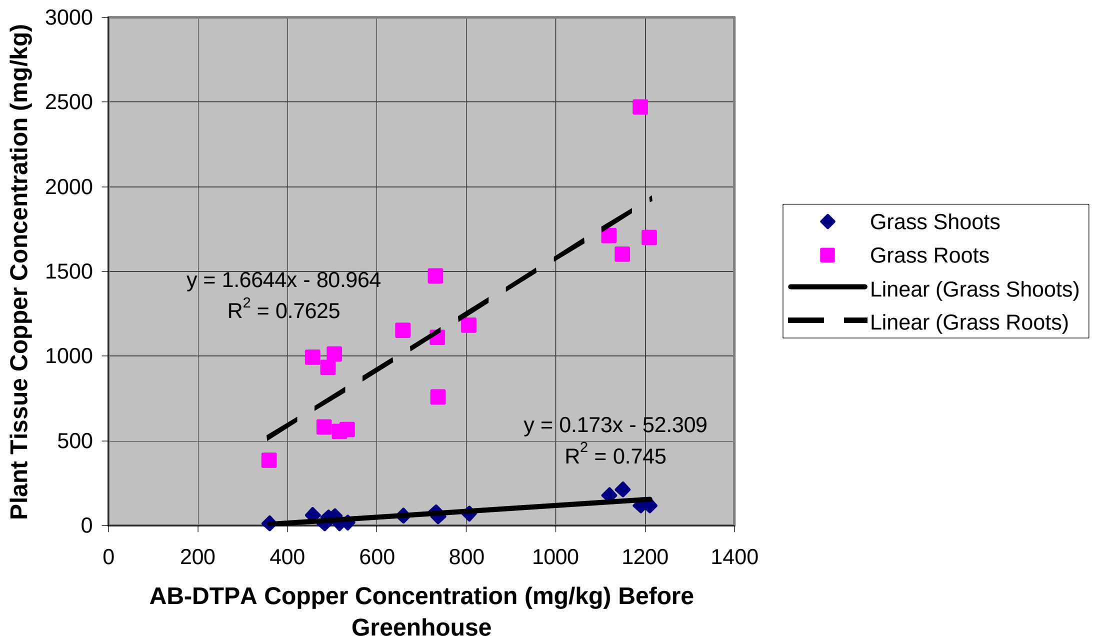
- Within the short time frame of the greenhouse trial (i.e., 12 weeks), additions of the organic amendments tested were not statistically demonstrated to significantly reduce plant availab1e copper in tailings. However based on the general trends in the data provided in **Figure 1** it was believed that over time OM would form stable complexes with plant available copper and maintain them in non-mobile forms thereby reducing plant availab1e copper in the tailings.

FIGURE 1. CONCENTRATIONS OF AB-DTPA EXTRACTABLE COPPER IN TAILINGS AND NATIVE SOIL BEFORE AND AFTER THE GREENHOUSE TRIAL



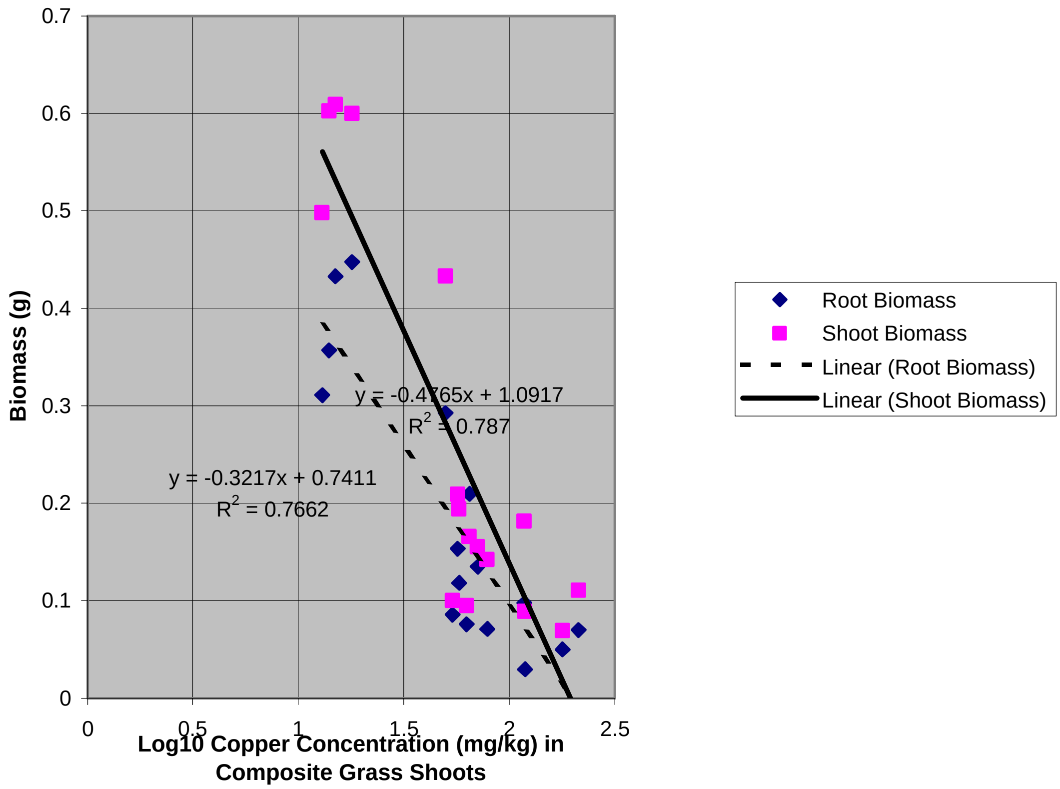
- Demonstrated the ability to predict plant metal uptake levels according to the “plant available” concentrations of copper in tailings (**Figure 2**).

FIGURE 2. RELATIONSHIP OF AB-DTPA COPPER CONCENTRATIONS IN TAILINGS TO COPPER CONCENTRATIONS IN COMPOSITE GRASS ROOT AND SHOOT TISSUE



- Demonstrated the effects of elevated copper levels found in the tailings on plant growth (**Figure 3**).

FIGURE 3. RELATIONSHIP OF COPPER CONCENTRATION IN COMPOSITE GRASS SHOOTS TO THE BIOMASS PRODUCTION OF COMPOSITE GRASSES



- Identified the deficiencies and application rates for the following plant-essential micronutrients and macronutrients:
  a. Boron
  b. Manganese
  c. Nitrogen
  d. Phosphorus

The findings from the greenhouse where incorporated into the large-scale revegetation field trials described below.

REVEGETATION FIELD TRIALS

The results of the greenhouse study, various erosion control measures and the recognition of all of the factors discussed above were incorporated into the design and implementation of large-scale revegetation field trials. The field trials were sufficiently sized to test the actual revegetation methods that would be used on-site. This effectively eliminated "edge effect" and eliminated the variable of installation method.

Considering the size of the tailings, small changes in the addition of OM and fertilizer resulted in substantial reductions in the cost of the tailings revegetation. Therefore, the rate of OM amendment decomposition in the tailings were evaluated during the field trial to further optimize and possibly reduce the required amount of OM and fertilizer addition.

The large-scale field trials were successfully installed on-site and thoroughly documented. All construction activities were performed under the direction and supervision of the designers of the revegetation plan. Trial designs are summarized below.

- Number of Plots – 162
- Plot Size – 1.0 and 0.5 acres
- Tailing Type –
    - Inaccessible –Wet
    - Inaccessible-Vegetated
    - Inaccessible-Barren,
    - Accessible –Barren
    - Coarse (Cyclone)Sand Embankment
- OM Rates - 0, 2, & 3%
- OM Type - Biosol, woodchips, wood pulp sludge, composted bark
- Erosion Control-
    - crimped straw
    - furrows
    - imprinting
    - dozer basins
    - slag & bark piles
    - incorporated slag
    - soil stabilizer

As part of the revegetation trials the relative rate of organic amendment decomposition was evaluated. The organic amendment decomposition evaluation was performed to refine the quantity and mixture of organic matter amendments applied to the tailings and identify the minimum amount of nitrogen fertilizer needed to prevent nitrogen immobilization. The information gained from this study was used to adjust nitrogen fertilization rates and organic amendments applied to the tailings.

The following recommendations resulted from observations made during both the installation of the field trials and full-scale implementation, as well as from a review of the project data. These recommendations are provided to demonstrate the level of difficulty encountered while working on mine tailings and to help future projects of this nature.

Major Findings from the Field Trials Recommendations

The major findings and recommendations resulting from the implementation and three years of monitoring of the field trials are provided below. Following each year of monitoring and based on experience gained during full-scale implementation modifications where made to the revegetation specifications for the next years revegetation activities.

- The vegetation frequency and overall species diversity of the 2 percent OM plots performed almost as well as the 3 percent OM plots.
- In comparison to the 3 percent OM plots, the 2 percent OM plots had a slightly greater total number of species, a higher frequency of volunteer species, and a higher number of species occurring in all plots.
- The composition of vegetation in woodchip and paper mill sludge plots was primarily timothy, smooth bromegrass and hairy vetch. Typically the greater species diversity on the reclaimed lands leads to greater site protection from climate extremes and disease. Therefore, the dominance of a reclaimed vegetation community by one or two species was not considered desirable.
- No single erosion control measure on the plots was substantially superior in terms of erosion protection. Therefore, the lowest cost method, crimped straw at 2 tons/acre, was considered the best erosion control method.
- Surface roughening of any type caught seed, fertilizer and moisture and was of benefit on inaccessible tailings when compared to no surface treatment.
- Based on the results from the OM decomposition study the following generalizations were made:
    a. Two years following reclamation net nitrogen mineralization (which increases the plant available nitrogen status of the soil in the short-term) was dominant.
    b. Based on the average loss of mass (on a dry weight basis) within litter bags filled with OM amendments the estimated decomposition rates over the two year monitoring period of woodchips, woodchip/paper mill sludge mixture, composted bark, paper mill sludge, and woodchips/composted bark mixture were 46.0%, 40.9%, 40.0%, 38.4%, and 29.4%, respectively. Based on the decline in the total organic carbon content of the organic amendments, which appeared to be more consistent and less variable than decomposition based on loss of mass, the estimated decomposition rates of paper mill sludge, woodchips/paper mill sludge mixture, woodchips, composted bark and woodchips/composted bark mixture lost were 83.3%, 77.3%, 70.3%, 67.5% and 54.2%, respectively.
    c. Following two growing season the majority of the added nitrogen fertilizer was depleted by plant uptake and microbial sequestration.
    d. The carbon: nitrogen ratio (C:N) of the organic amendments tested were below or near the ratio that is typically considered to result in net nitrogen mineralization (i.e. 25:1)
    e. The rapid decomposition of woodchips and composted bark was likely due to the high amount of inorganic fertilizer added to the trial and likely resulted in a

large production of microbial biomass with a low C:N ratio (active nitrogen pool).

f. A slight decrease in Total Kjeldahl Nitrogen (TKN) of woodchips and composted bark between 1999 and 2000 was observed. This was estimated to be the result of the mineralization of nitrogen contained in microbial biomass (active nitrogen pool) produced in previous years from the application of fertilizer nitrogen and a relatively high C:N ratio carbon source (i.e. organic amendment). Therefore, the majority of nitrogen mineralization in subsequent years will likely be the result of the mineralization of soil microbial biomass rather than the decomposition of OM amendments.

- Vegetation production in the 2 and 3 percent OM plots and the tailings reclaimed in 1999 was extremely high. Based on visual observations it was estimated that vegetation production was between 4,000 - 5,000 lbs/acre (dry weight basis). In addition, plant litter accumulation was extremely high in the plots. It was anticipated that litter accumulation in areas reclaimed in 1999 areas would also be extremely high. While this provided erosion protection it would likely not be sustainable. As a result, revisions to the fertilizer recommendations and seed mixture specifications, were recommended (See below).
- Based on the performance of tall fescue (tested on other plots performed on site) and mammoth wildrye it appeared that these species may compete well with dominant redtop on the vegetated portions of No. 1 Tailings.
- Surface applications of woodchips and/or crimped straw appeared to be an effective method of reducing the dominance of redtop on the vegetated portions of No. 1 Tailings.
- It appeared that low water holding capacity was the main reason for poor vegetation performance on the coarse (cycloned) sand embankment plots.

Recommended Revegetation Modifications Based on Field Trial Monitoring

Based on the conclusions listed above, modifications to the next year's revegetation activities were provided. These modifications where as follows:

- Incorporate woodchips/paper mill sludge as a rate of 2% and eliminate the application of inorganic fertilizer.
- Apply woodchips that have a coarse particle size distribution
- Remove timothy from the seed mixture if the straw mulch crimped into the surface of the tailings has a high percentage of timothy.
- Apply the seed mixture provided below in **Table 6**

TABLE 6
NO. 2 TAILINGS
RECOMMENDED
STANDARD SEED MIXTURE
FOR FULL TREATMENT AREA IN 2001

Scientific Name	Common Name	Pounds Of PLS[1] Per Acre[2]
Forbs		
Medicago sativa	Alfalfa	1.87
Vicia villosa	hairy vetch	5.0
Trifolium hybridum	alsike clover	0.48
Trifolium pratense	Red clover	5.0
Trifolium Repens	White Dutch clover	5.0
Graminoids		
Dactylis glomerata	orchardgrass	2.17
Bromopsis inermis	smooth bromegrass	1.3
Elymus racemosa	mammoth wild-rye	7.5
Phleum pratensis	timothy	0.6
Festuca arundinacea	Tall fescue	4.0
Festuca rubra	creeping red fescue	1.07
Festuca trachyphylla	hard fescue	0.59
Deschampsia caespitosa	Tufted hairgrass	0.31
Arctagrostis latifolia	polargrass	0.44
Agrostis alba	redtop	0.14
TOTAL		**35.16**

[1]PLS - Pure Live Seed.

[2]Pounds PLS/acre may vary depending upon actual seeds per pound for each seed lot.

- Cut and bale vegetation from previous years revegetation and for use as a surface mulch for the next years revegetation activities.
- For the cycloned sands tailings embankments of No. 2 Tailings the following recommendations were made:
  a. Incorporate paper mill sludge and woodchips to the coarse (cycloned) sands embankments at a rate of 4% OM or 36.8 and 94.7 tons tons/acre, respectively.
  b. Apply the standard fertilizer recommendation plus 60 lbs elemental nitrogen /acre (preferably ammonium nitrate).
  c. Apply 2 tons/acre straw mulch and crimp into the surface of the coarse (cycloned) sands embankments.
  d. Apply the seed mixture as shown below in **Table 7**.

TABLE 7
CYCLONED SANDS TAILINGS EMBANKMENT RECOMMENDED STANDARD SEED MIXTURE IN 2001

Scientific Name	Common Name	Pounds Of PLS[1] Per Acre[2]
Forbs		
Medicago sativa	alfalfa	1.87
Vicia villosa	hairy vetch	10.89
Trifolium hybridum	alsike clover	0.48
Graminoids		
Dactylis glomerata	Orchardgrass	2.17
Bromopsis inermis	smooth bromegrass	2.61
Elymus racemosa	mammoth wild-rye	5.06
Phleum pratensis	timothy	1.27
Festuca rubra	creeping	1.07

**TABLE 7
CYCLONED SANDS TAILINGS
EMBANKMENT
RECOMMENDED
STANDARD SEED MIXTURE IN 2001**

Scientific Name	Common Name	Pounds Of PLS[1] Per Acre[2]
	red fescue	
Festuca trachyphylla	hard fescue	0.59
Deschampsia caespitosa	Tufted hairgrass	0.31
Arctagrostis latifolia	polargrass	0.44
Agrostis alba	redtop	0.14
Secale cereale	cereal rye	22.53
Hordeum vulgare	barley	46.67
TOTAL		**96.1**

[1]PLS - Pure Live Seed.
[2]Pounds PLS/acre may vary depending upon actual seeds per pound for each seed lot.

e. Pockmark the surface of the cycloned sands embankments. Pockmarks should be approximately 25% the size of the dozer basins on the Coarse (cycloned) Sand Plots. Pockmarks should be irregularly placed and cover the entire surface of the embankment.

- For the voluntarily vegetated tailings areas the following recommendations were made:
  - Apply the recommended revised seed mixture for the No 2 Tailings as shown above.
  - Apply paper mill sludge and woodchips on the surface at a rate of 1% OM or 9.2 tons/acre and 23.75 tons/acre, respectively.
  - Straw mulch the areas at a rate of 2 tons/acre and where inundation is likely, crimp the straw into the surface of the tailings.

Equipment and Implementation Recommendations

- Use low ground pressure tractors such as Caterpillar Challengers to pull various implements. Retrofit tractors and implements with wide tracks or flotation tires.

- Ensure that machine balance is appropriate for the implement being pulled by the tractor. Use front mounted counterweights when appropriate to shift loads away from the rear axle.
- Use side-cast manure spreaders for OM application to avoid traffic over inaccessible wet tailings.
- Prescreen and inspect OM amendment for debris and foreign objects to avoid jamming and breaking of augers on spreading equipment.
- ATVs may be used for an assortment of tasks in rough and boggy terrain typical of tailings facilities.
- Inform equipment operator of potential trouble spots and the methods to avoid getting equipment stuck in the tailings.
- Sharply turning Cat Challengers equipped with spreaders or other implements at the start or end of runs created imbalance. This was the most common reason for getting equipment stuck. Avoid this problem by performing wide gentle turns.
- Once equipment becomes trapped in tailing methodically consider and evaluate extraction methods to avoid getting more equipment stuck.
- Immediately mulch areas following seeding to avoid seed loss.
- Plan and layout operation areas and sequence to meet QA/QC and time objectives.

FINAL REVEGETATION SPECIFICATIONS/QUALITY ASSURANCE AND SUCCESS MONITORING

Based on the results from the field trials, financial constraints and mine management, specifications for the revegetation of the site were developed and modified according to field trial monitoring and experience gained during full-scale implementation. The specifications included methods of ameliorating the tailings to address the chemical and physical issues identified in the tailings analyses, greenhouse study and field trials. Plant species and rates (including specific varieties) proven to be successful in the greenhouse study and based on performance in the field trials were specified for use. Cultural techniques, which address meteorological constraints such as wind blown tailings, precipitation, planting times, etc., were also specified.

Revegetation plan designers performed oversight of the revegetation installation . Oversight included preparation of bid specifications and requests for proposals, identification of revegetation materials such as seed, fertilizers, soil ameliorants, mulches and erosion control products, selection of contractors, supervision of the installation and the monitor of revegetation success over time.

CONCLUSIONS

Through the systematic approach discussed above the key factors that ultimately dictated revegetation success at the White Pine Mine Tailings were identified. As a result reclamation techniques were formulated, evaluated, revised and improved upon. The greenhouse study demonstrated the benefits of OM amendments and identified soil analytical methods that are capable of predicting critical copper levels in plants. Plant tissue analysis accomplished during the greenhouse study emphasized the need to identify, procure, and propagate copper-tolerant plants that were adapted to the local climate conditions. The field trials identified equipment limitations including the maximum ground pressure tolerated on the tailings and payload capacity. Overtime, information from the field trials enable the selection of the most appropriate erosion control methods, eliminated the use of inorganic fertilizers and confirm the performance of OM treatments and plant species selected for the site.

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